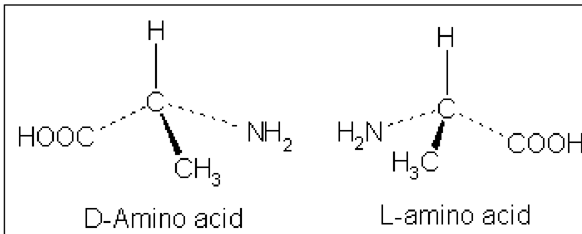
Parity Violation



Optical isomers. Both amino acids have the same numbers of hydrogen (H), carbon (C), oxygen (O), and nitrogen (N) atoms. They are identical with respect to ordinary chemical reactions, however neither structure can be superimposed upon the other to match up the chemical groups. Spearmint chewing gum and Caraway seeds, respectively, contain *L-carvone* and *D-carvone*—optical isomers of carvone. These taste differently to most people because our taste receptors also contain molecules which behave differently in the presence of different isomers. D-form amino acids tend to taste sweet, whereas L-forms are usually tasteless. The smells of oranges and lemons are also examples of the D and L isomers affecting biological systems differently.

In 1848, Louis Pasteur discovered, almost by sheer luck, the property of *optical isomerism* (see the figure at right). Isomers are chemically identical compounds—having the same number and type of atoms and the same structure, almost. The difference in the two isomers of a compound is that one is the mirror image of the other. This is the same symmetry that exists between the left and right hands. Because of this property, when polarized light strikes the two isomer forms of the same chemical compound, each isomer rotates the polarized light in a different direction—one to the left, the other to the right. Pasteur observed as well that living organisms were able to synthesize and use either one isomer or the other—but never one isomer *and* its opposite in the same way. But nature itself appears to have no preference over which form it produces—in chemical reactions, the isomers are produced in equal quantities. That is, nature appears to exhibit complete symmetry between the left and right. Until 1957, physicists believed this symmetry to hold for all physical processes. A mirror image of any reaction should be identical in every way to the actual reaction—an idea that was intuitive to the physicist. To describe more precisely the symmetry between left and right, physicists used the concept of *parity*.

Parity originated with the development of quantum mechanics. In 1924, Otto Laporte classified the wavefunctions of an atom as either even or odd, depending upon the symmetry of the wavefunction. Laporte discovered that when an atom transitions from one state to another and a photon is emitted, the wavefunction changes from even to odd or vice-versa, but never remains the same. *Even* wavefunctions were defined to have parity of +1; *odd* wavefunctions a parity of -1. The importance of parity conservation, and its fundamental nature, was discovered in 1927 by the physicist Eugene Wigner, who proved that Laporte's rule was a consequence of left-right symmetry (or mirror image symmetry) of the electromagnetic force. Conservation of parity rested upon Maxwell's equations describing electromagnetism; but more importantly, the intuitive idea that nature should be left-right symmetric had been established on the quantum level.

Within the cosmic rays in which Cecil Powell had discovered the pi meson (pion) were other new particles. In 1949, Powell identified a cosmic-ray particle that disintegrated into three pions (the tau meson). Another particle called the theta meson was also discovered. It disintegrated into two pions. Both particles disintegrated via the weak force. The two particles turned out to be indistinguishable other than their mode of decay. Their masses and lifetimes were identical, within the experimental uncertainties. Were they in fact the same particle? The problem itself was not that the tau and theta, if indeed they were the same particle, decayed in two different modes: one by two pions, the other by three pions. The problem dealt with the more fundamental parity conservation law. In 1953, the physicist Richard Dalitz argued that because the pion has parity of -1, two pions would combine to produce a net parity of $(-1)(-1) = +1$, and three pions would combine to have total parity of $(-1)(-1)(-1) = -1$. Hence, if conservation of parity holds, the theta should have parity of +1, and the tau of -1. Hence, they could not be the same particle. Thus was born the "theta-tau puzzle," the resolution of which would involve an almost unacceptable proposition to the physicists of the time—perhaps conservation of parity did not hold in weak interactions. Violation of parity conservation through weak interactions was ultimately confirmed in experiments in late 1956 and early 1957. Since then, physicists have been striving to understand and explain this phenomenon.